



Seasonally Dependent Impact of Cloud Longwave Scattering on the Polar climate and Energy Cycle

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Based on a paper recently submitted: Chen, Y.-H., et al., “Seasonally dependent impact of cloud longwave scattering on the polar climate”

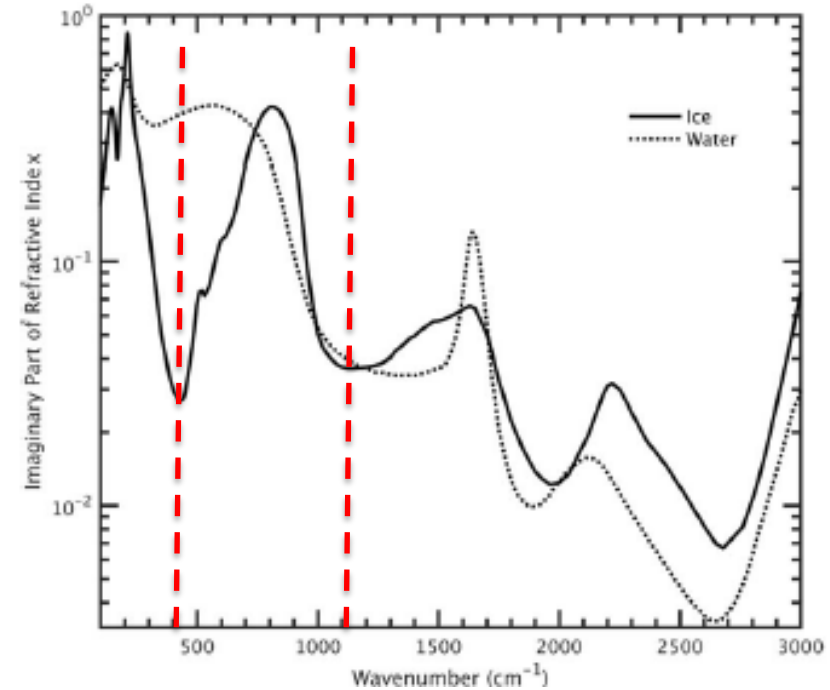
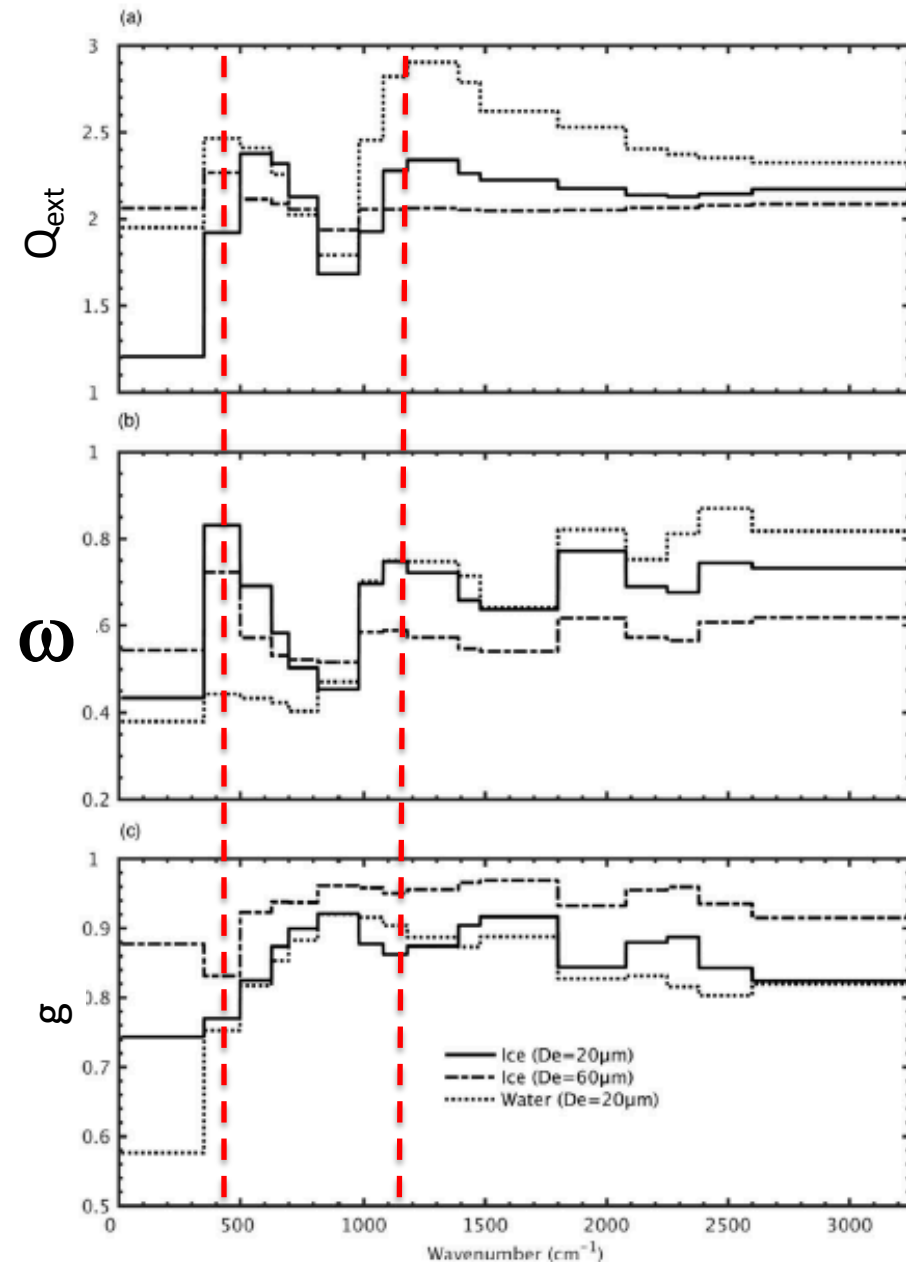


Outline

- Define the problem
- The traditional wisdoms in climate/weather modeling
 - Non-scattering cloud in the longwave
 - Blackbody surface in the longwave
- Why and where do the wisdoms break down?
- What is the impact on the simulated climate?
- The importance of coupling
- Conclusions and Outlooks

Take-home messages: traditional wisdom breaks down in the polar region, and (far-IR) LW scattering matters for the surface-atmosphere radiative coupling there.

In reality: Cloud LW properties



$\text{Im}(\mathbf{n})$ minimum \longleftrightarrow Scattering peaks

ω : single-scattering albedo

$\omega = 1$: 100% scattering

$\omega = 0$: 100% absorption

Scattering + Absorption = extinction/attenuation

(Kuo et al, 2017, JAMES)

In models:

only 3 out of 30+ models assumes cloud being non-scattering in the longwave

4.9.5 Cloud emissivity

The clouds in CAM 4.0 are gray bodies with emissivities that depend on cloud phase, condensed water path, and the effective radius of ice particles. The cloud emissivity is defined as

$$\epsilon_{cld} = 1 - e^{-D\kappa_{abs}CWP} \quad (4.375)$$

where D is a diffusivity factor set to 1.66, κ_{abs} is the longwave absorption coefficient (m^2g^{-1}), and CWP is the cloud water path (gm^{-2}). The absorption coefficient is defined as

$$\kappa_{abs} = \kappa_l(1 - f_{ice}) + \kappa_i f_{ice} \quad (4.376)$$

where κ_l is the longwave absorption coefficient for liquid cloud water and has a value of 0.090361, such that $D\kappa_l$ is 0.15. κ_i is the absorption coefficient for ice clouds and is based on a broad band fit to the emissivity given by Ebert and Curry's formulation,

$$\kappa_i = 0.005 + \frac{1}{r_{ei}}. \quad (4.377)$$



Also in 30+ models:
surface emissivity has no spectral
dependence in any surface modules
and
surface is assumed to be blackbody in
the atmospheric modules



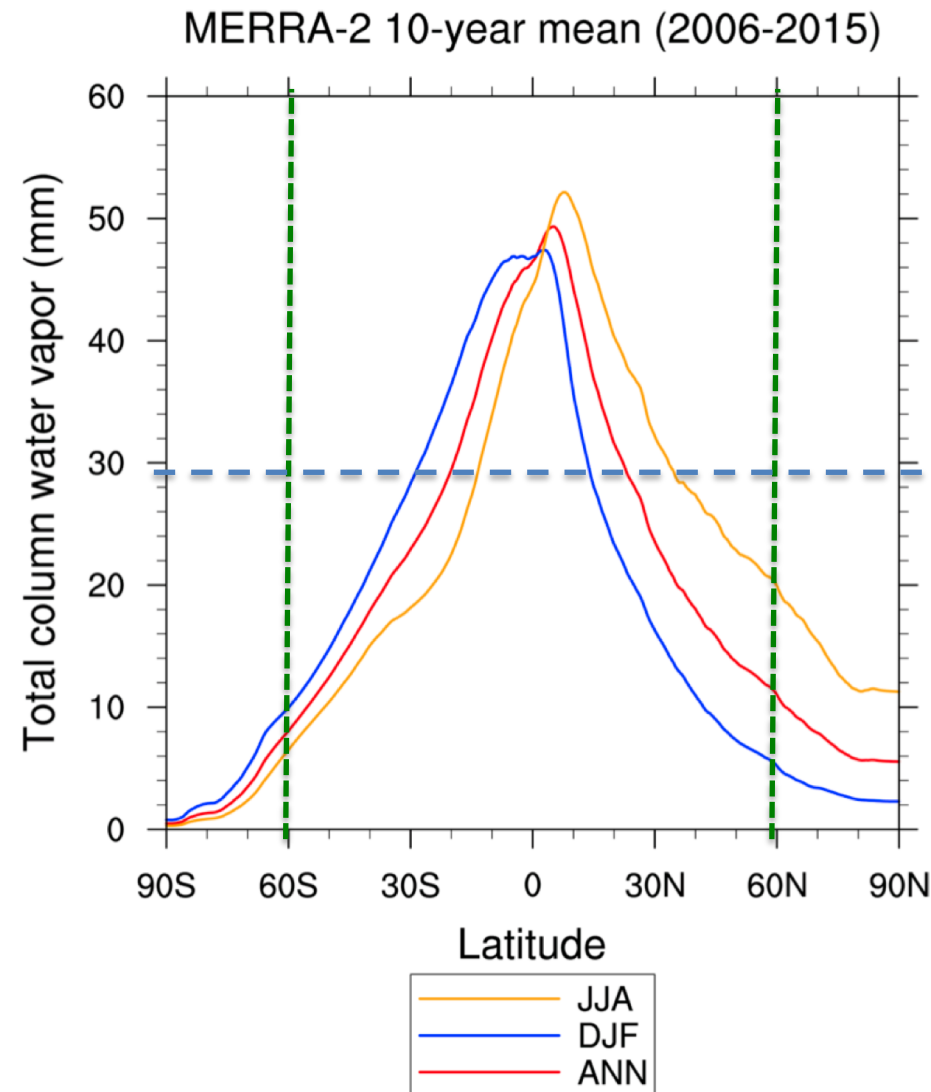
Why do such approximations?

- GCMs have been developed for decades. Don't brush off the traditional wisdoms easily
- However, two facts need to be considered
 - Traditional focus in on the tropics and mid-latitude.
 - Polar is a focus only recently.
 - How to make a decision for a scheme related atmospheric physics?
 - Run, compare, and make decision
 - How to run it? AMIP run, SOM run, or fully-coupled run??

When radiation scheme was developed decades ago ...

- Polar region is not a focus.
- Water vapor abundance changes a lot from the tropics to polar regions

$$\tau_{H_2O} \propto \rho_{H_2O}$$

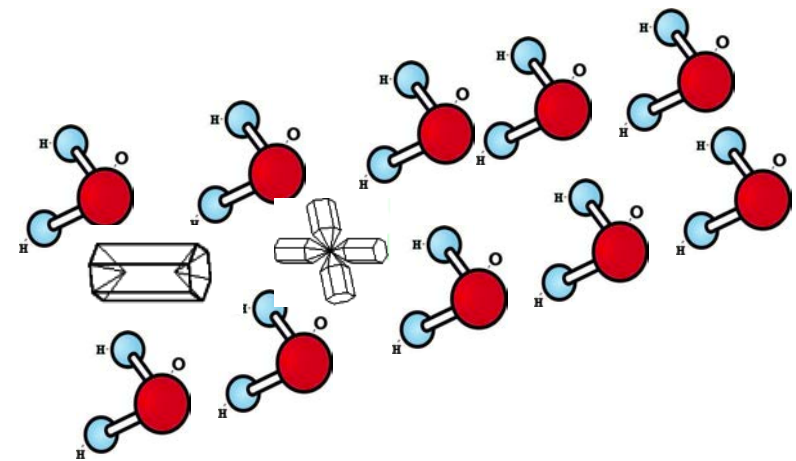
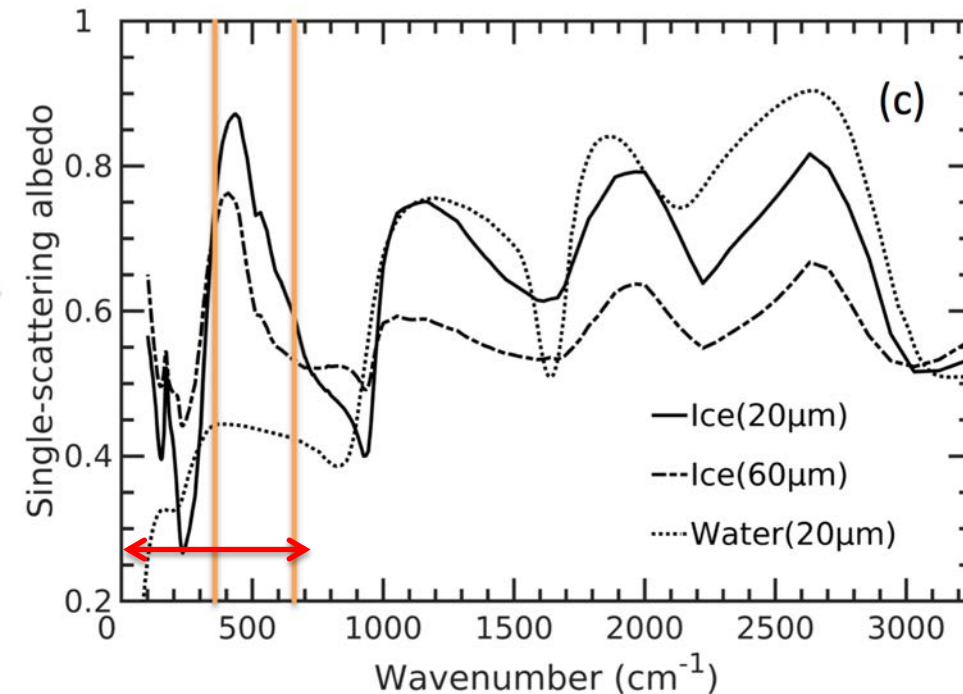


The aftermath of small TCWV in polar regions (I)

$$\omega_{layer} = \frac{\omega_{cld} \tau_{cld}}{\tau_{H_2O} + \tau_{cld}}$$

$\tau_{H_2O} \gg \tau_{cld}, \omega_{layer} \rightarrow 0$ Tropics & mid-latitudes

But now τ_{H_2O} reduced by 10 or even more...

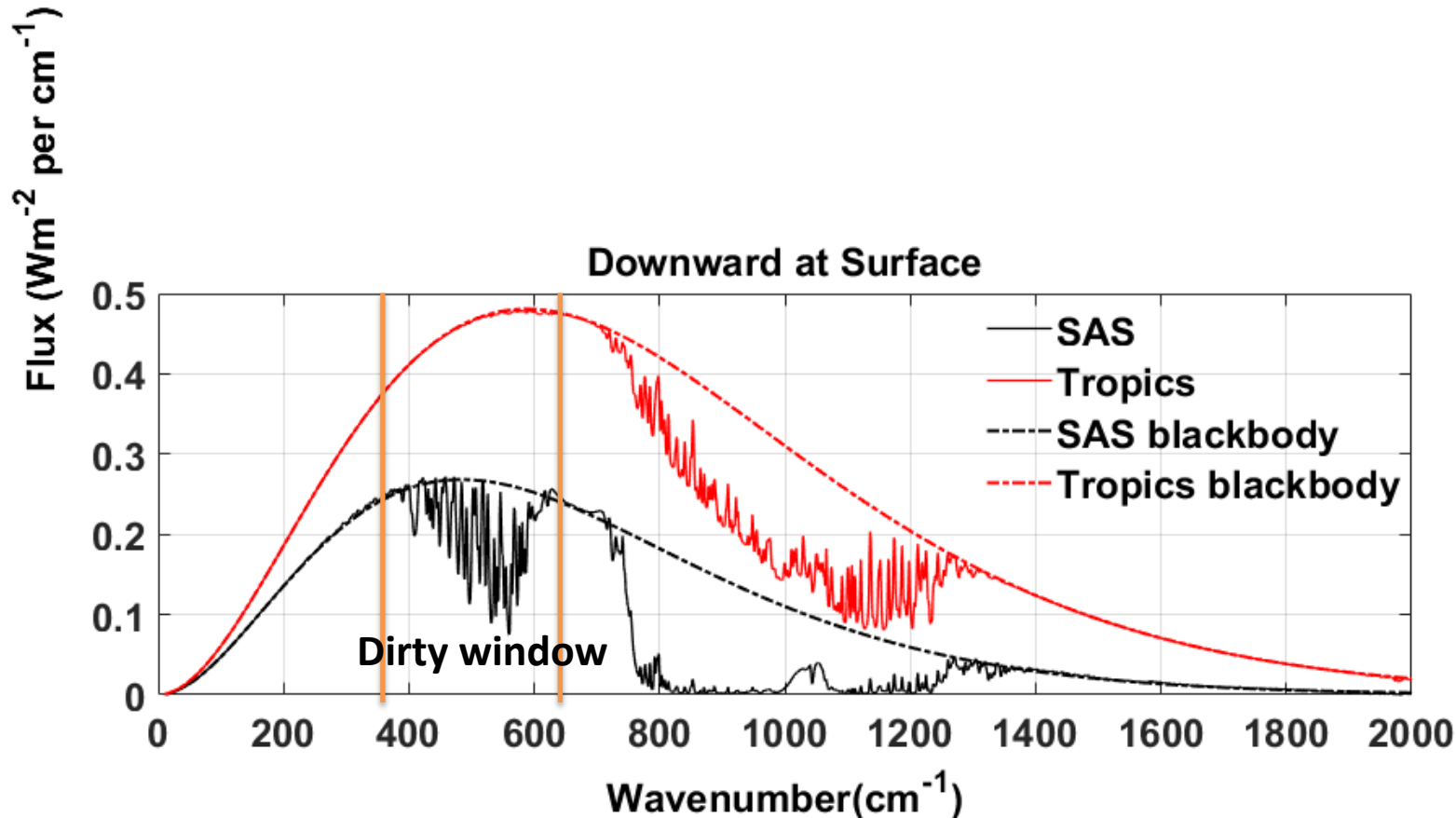


Far IR: Strong H_2O absorption
 Two RRTMG far-IR bands

The aftermath of small TCWV in polar regions (II)

$$F^\uparrow(\nu) = \varepsilon(\nu)\pi B_\nu(T) + [1 - \varepsilon(\nu)]F^\downarrow(\nu)$$

$$= \varepsilon(\nu) \left[\pi B_\nu(T) - F^\downarrow(\nu) \right] + F^\downarrow(\nu)$$

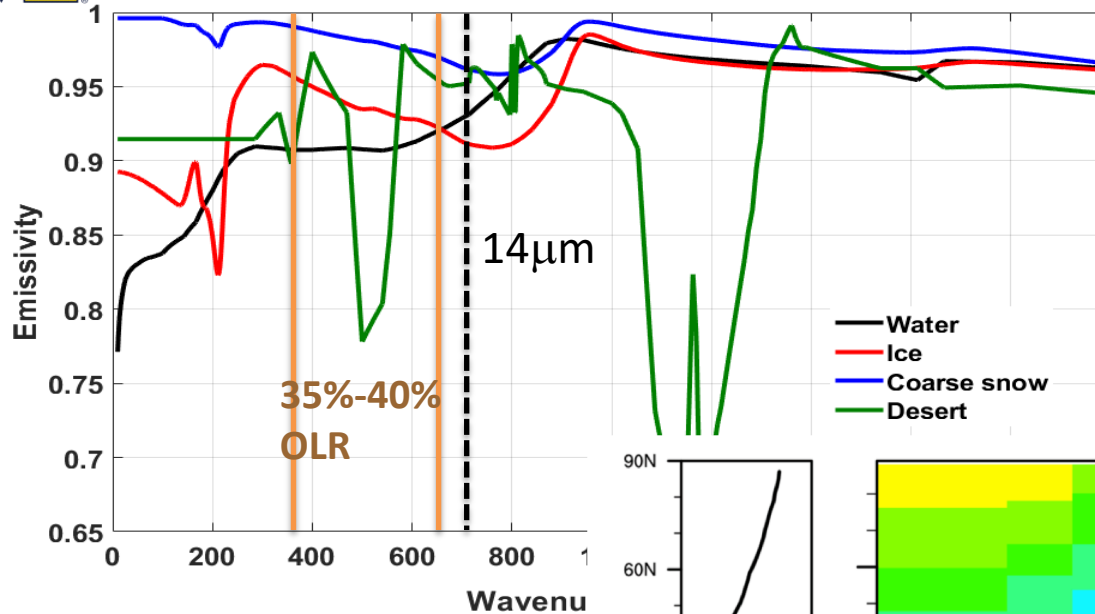


SAS: subarctic
summer
(60°N)

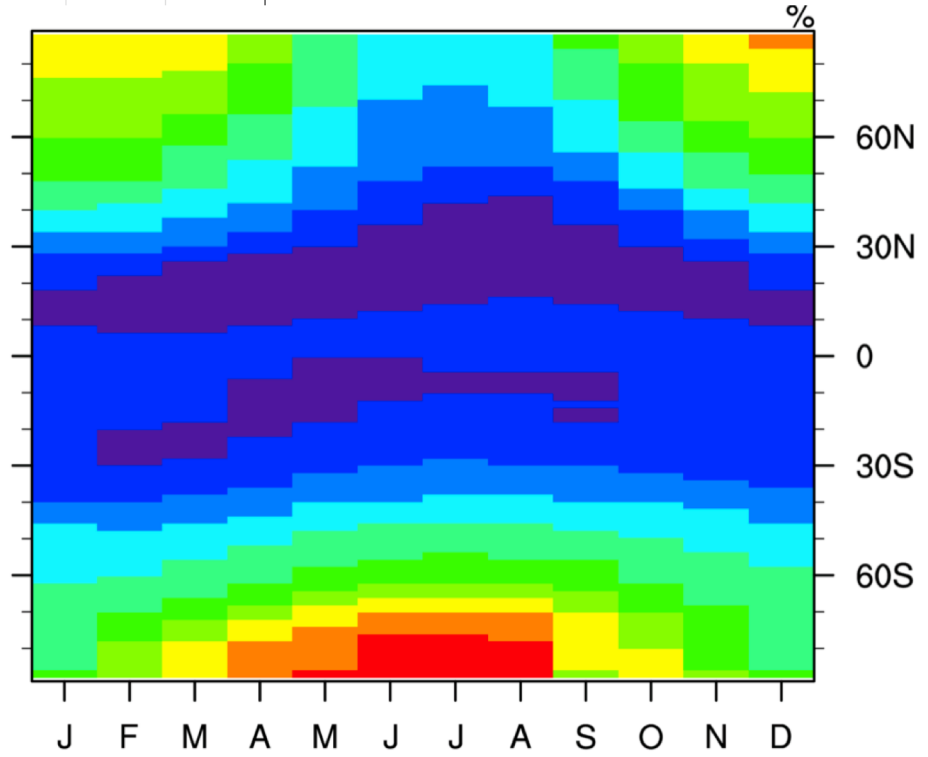
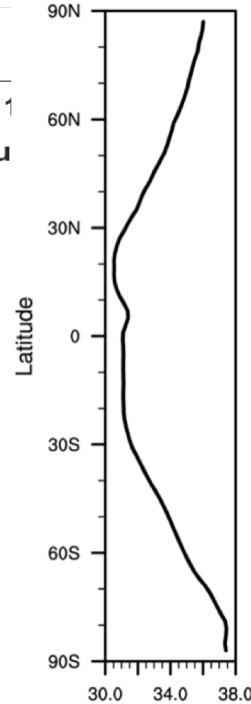


Surface spectral emissivity $\varepsilon(\nu)$ is not one

Broadband emissivity won't work



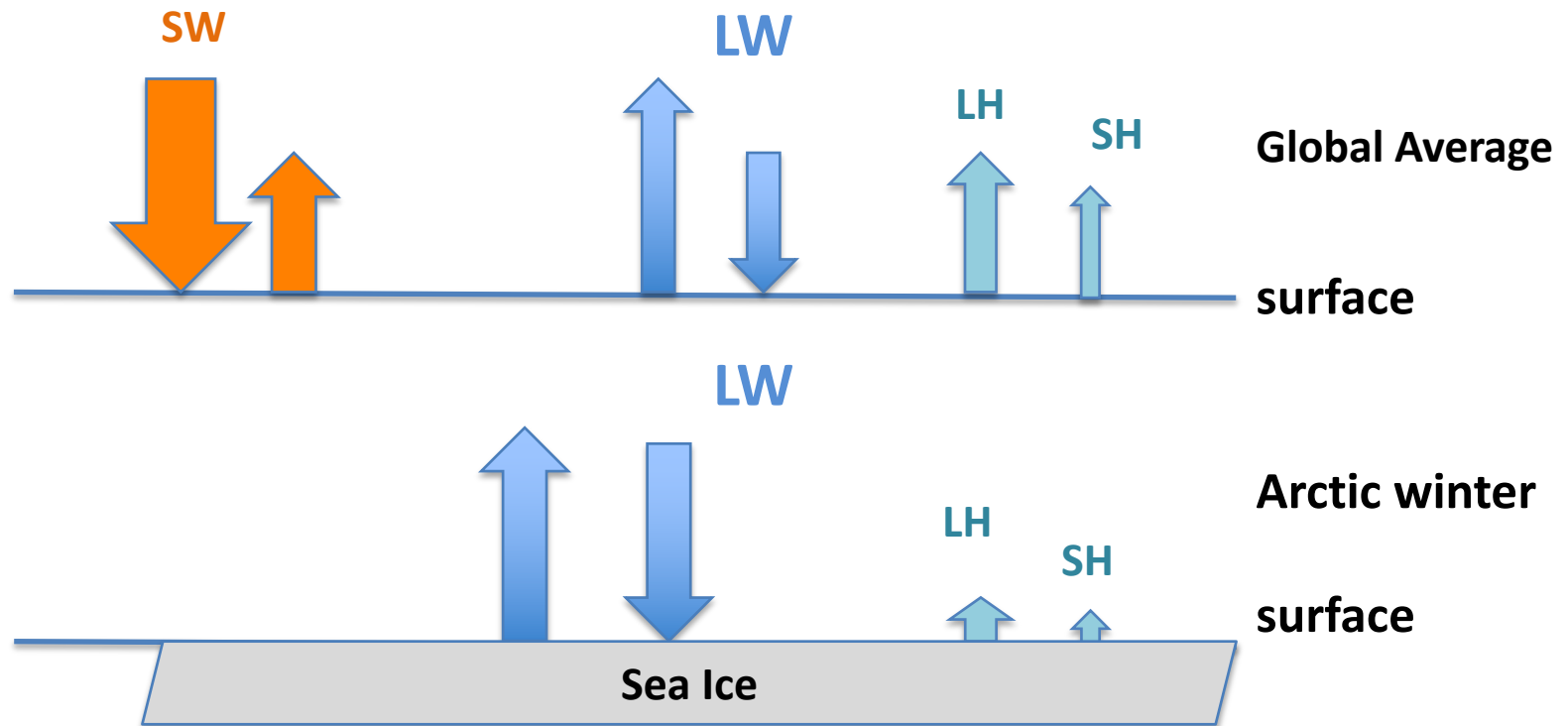
Two RRTMG bands to OLR



31 32 33 34 35 36 37 38 39

Excursus: desert region/window band (Chen et al., 2019)

On top of above considerations: seasonality matters



Hypothesis: missing LW processes would affect Arctic winter T_s the most, which then affects subsequent processes and feedbacks.

Real World

GCM World

(Chen et al., 2014)

emission/absorption

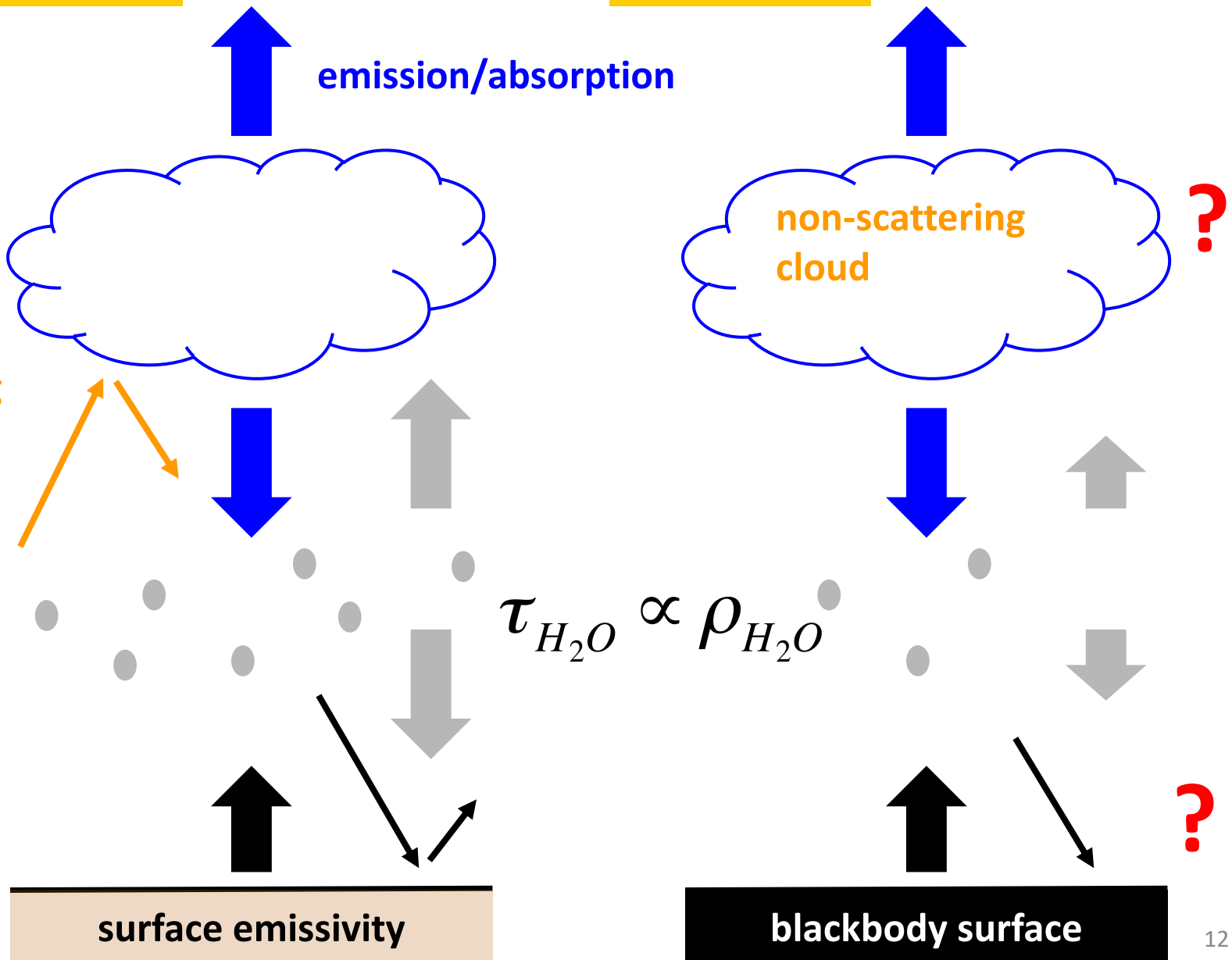
scattering

non-scattering
cloud

$$\tau_{H_2O} \propto \rho_{H_2O}$$

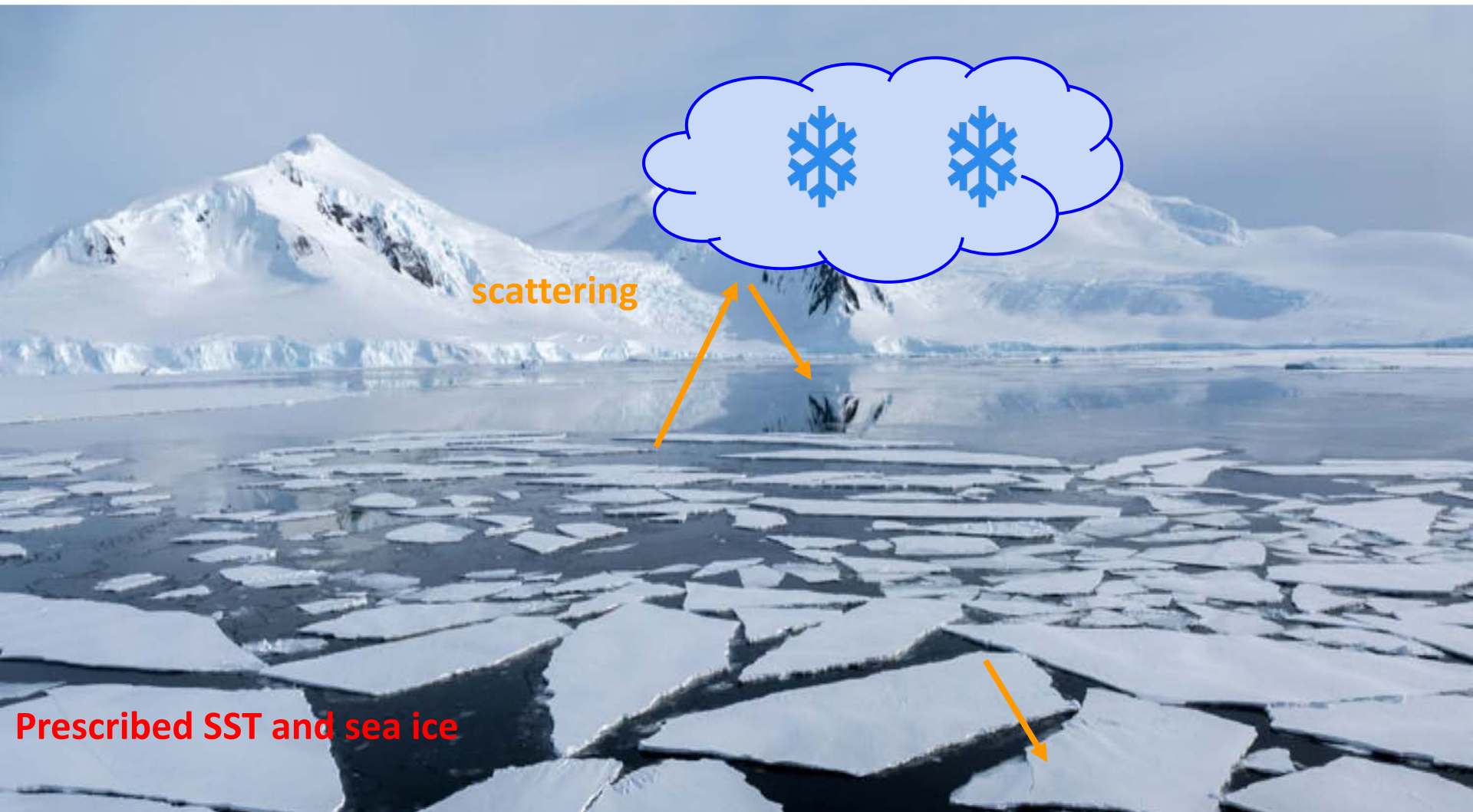
surface emissivity

blackbody surface



Previous studies on cloud LW scattering always used AMIP-type prescribed SST/sea ice runs.

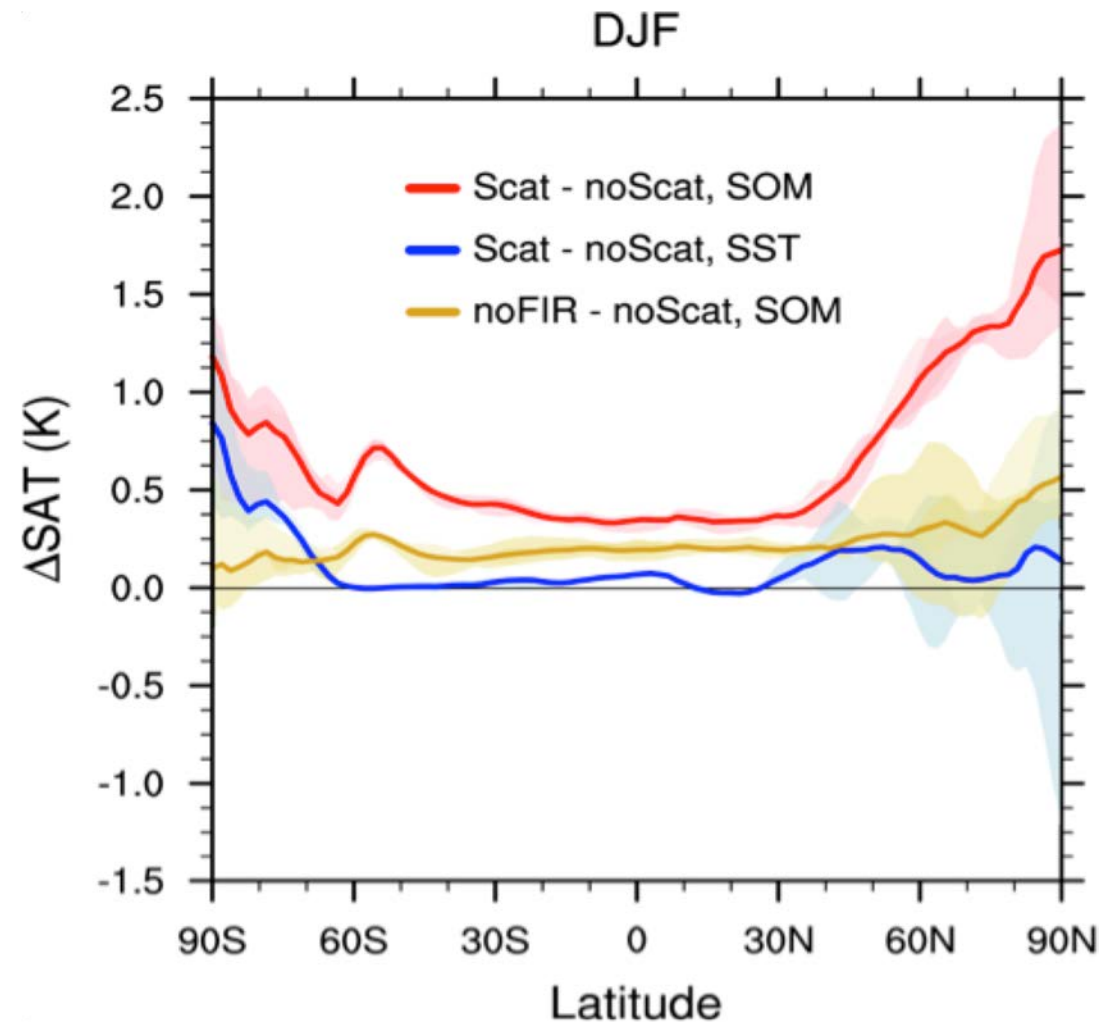
Hypothesis: without surface responses to the cloud LW scattering, its effect cannot be fully revealed.



Implementations

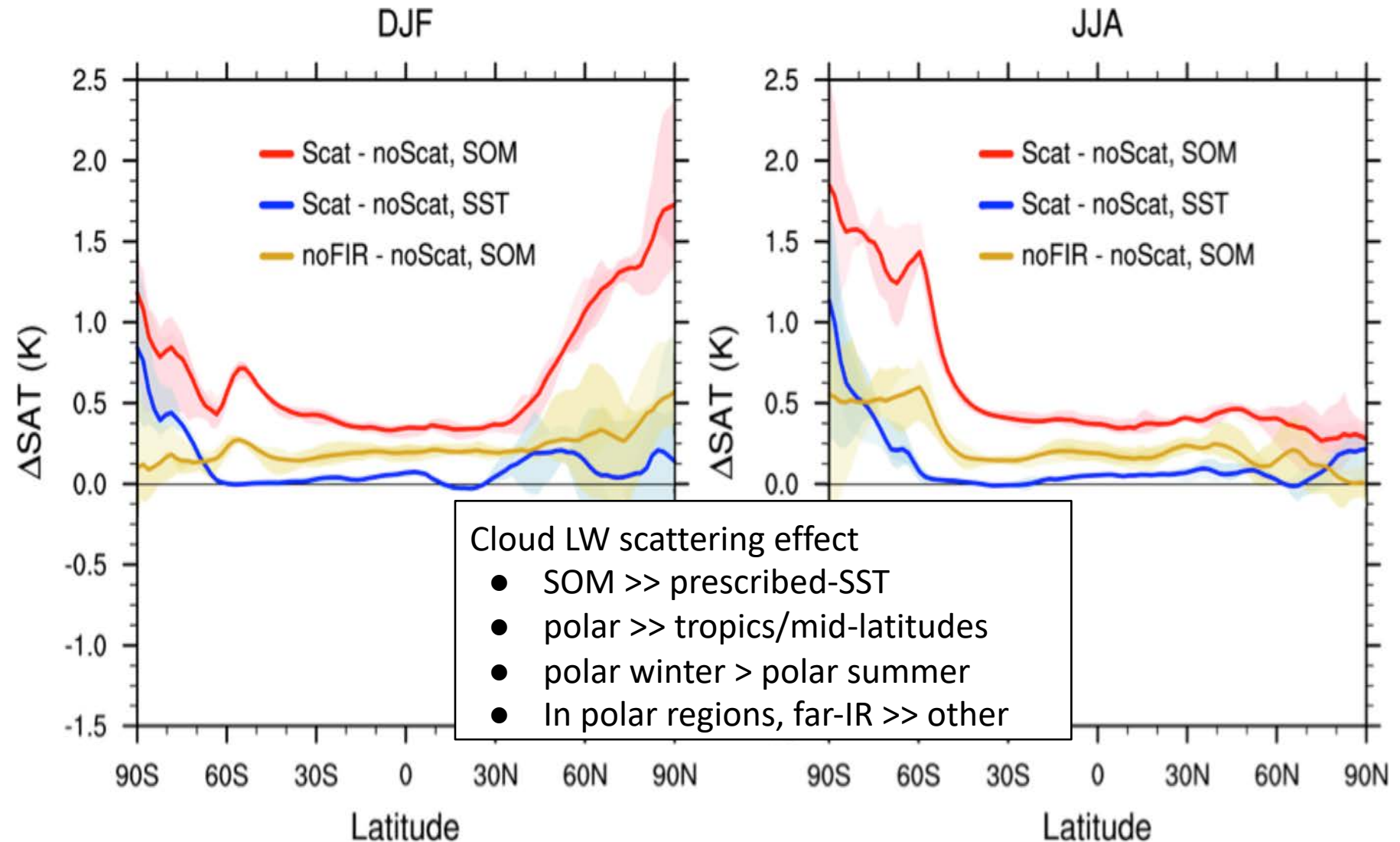
Ice cloud	<ul style="list-style-type: none">• MC6 ice cloud optics• A hybrid 2S/4S LW scattering solver into RRTMG_LW (Toon et al., 1989; Kuo et al., 2020)
Surface spectral emissivity	<ul style="list-style-type: none">• Based on the spectral emissivity database (Huang et al., 2016)• Prescribed land spectral emissivity• Prognostic spectral emissivity over sea ice and ocean• Major conclusions in Huang et al. (2018, J. Climate)
Control case:	CESM v1.1.1/DoE E3SM v1

Diff of surface air temperature



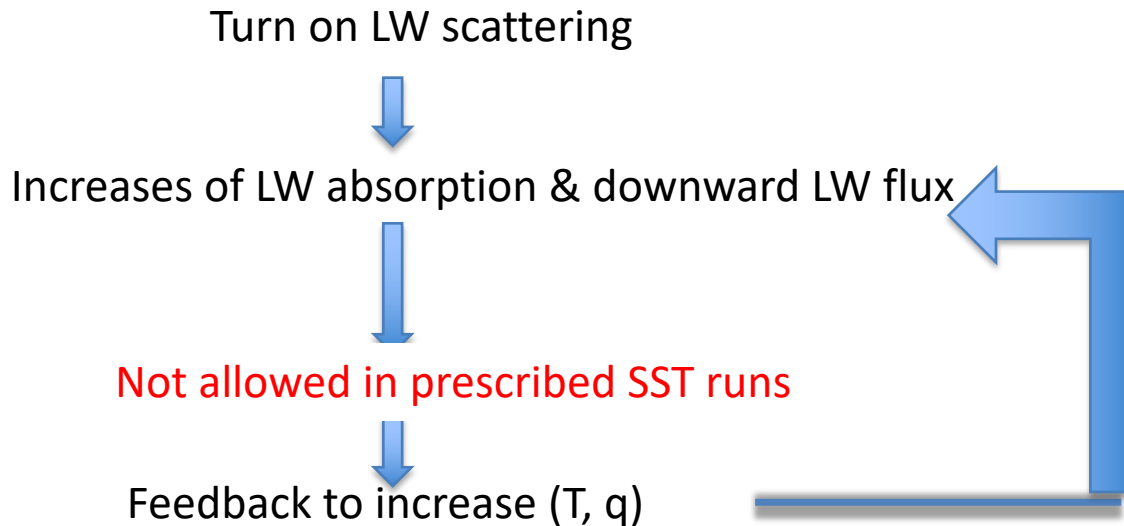
SST: prescribed SST run
 SOM: slab-ocean run (surface-atmosphere coupling enabled)

Diff of surface air temperature



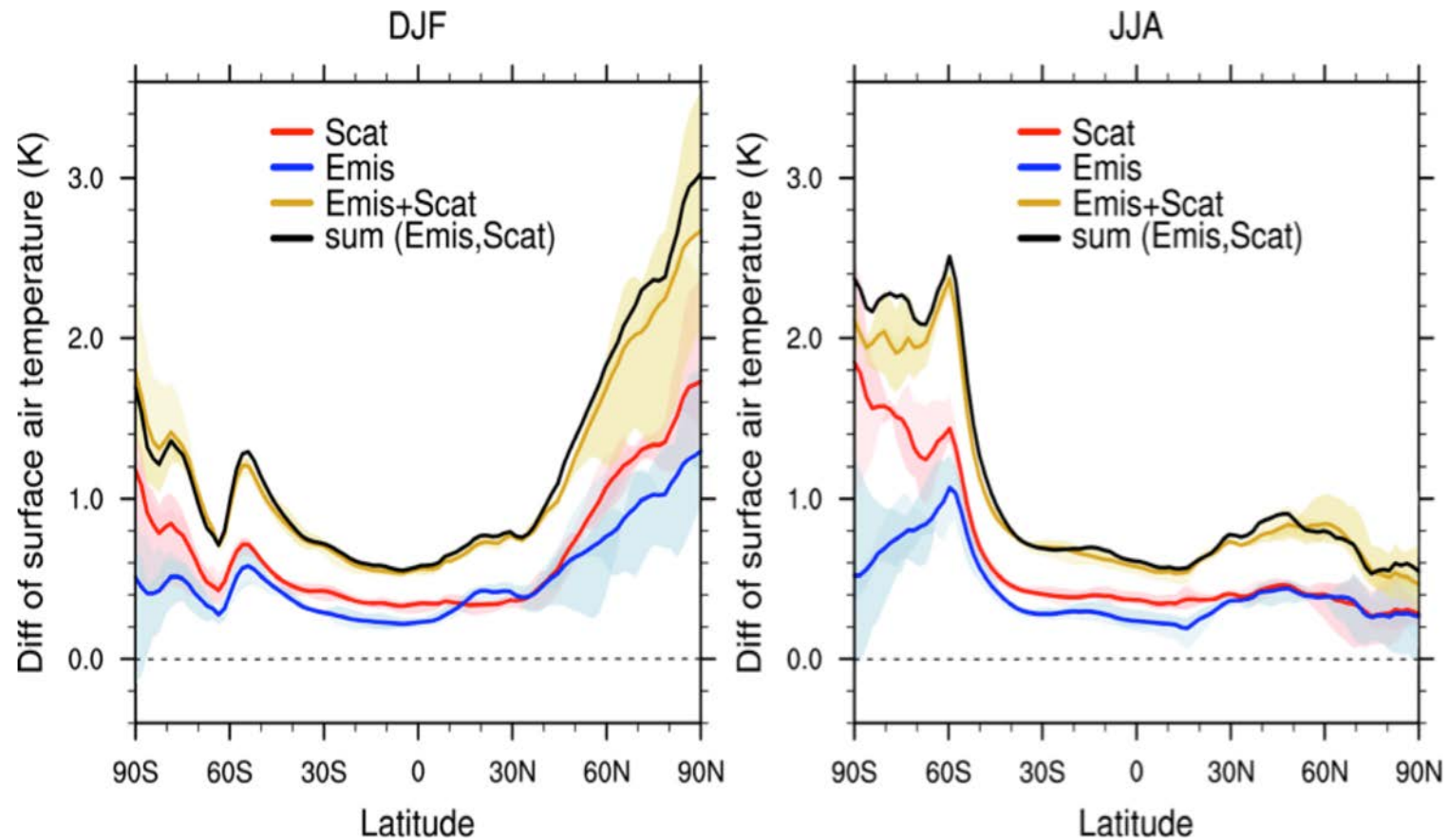
Why LW scattering was ignored?

- Tropics/mid-latitude focus
- The decisions were made with AGCM run only: prescribed SST/sea ice
- The surface-atmosphere LW coupling **manifests** the LW scattering effect



When realistic surface emissivity is also included

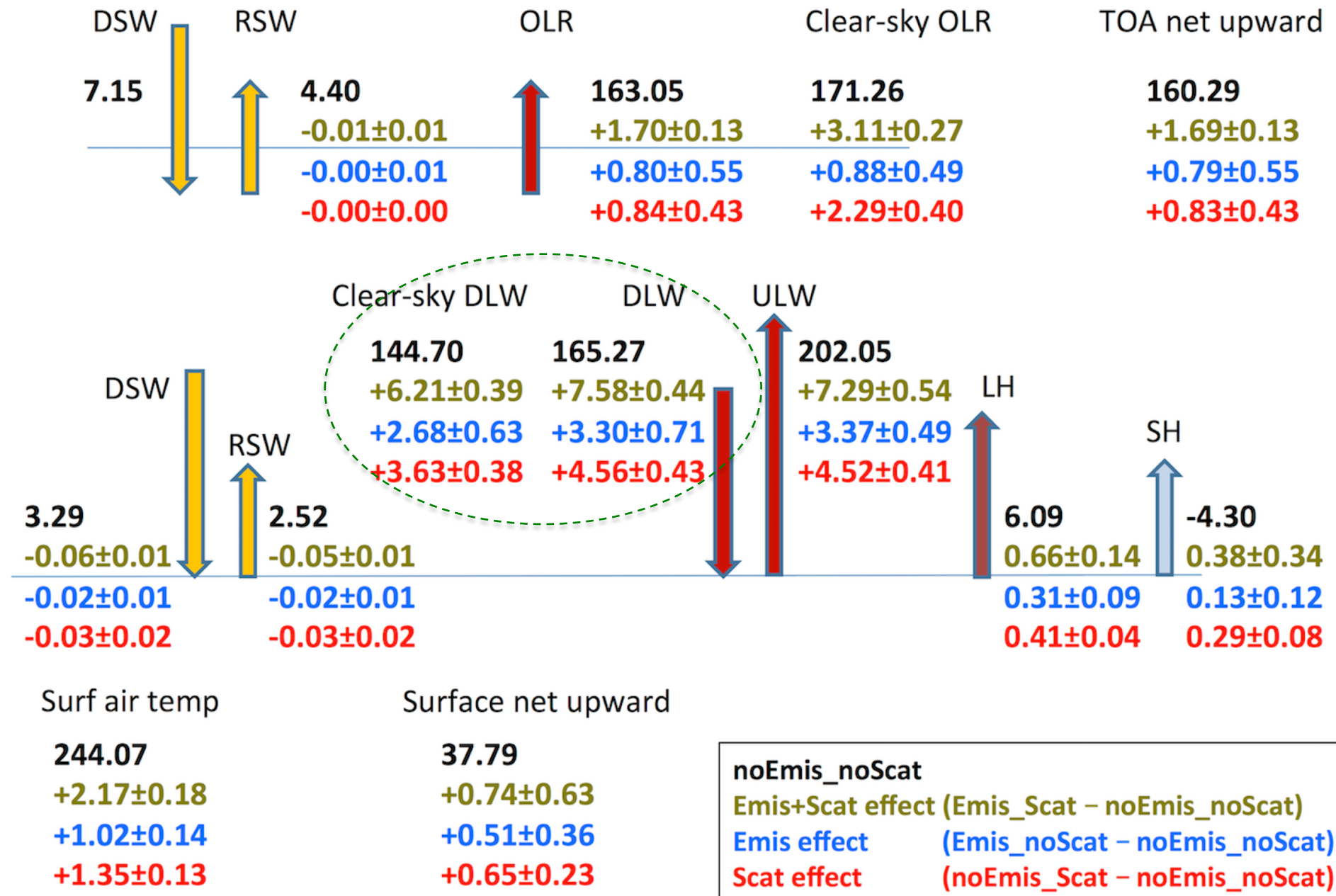
Changes in surface air temp



Emissivity and scattering effect is comparable and the combined effect is largely linear additive.



DJF climatology energy budget over the Arctic (66.5°-90°N)





Conclusions and discussions

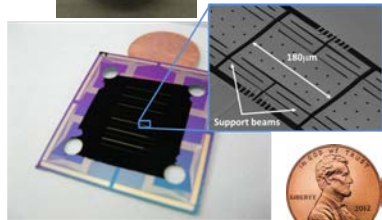
- LW scattering and surface spectral emissivity: two missing LW physics in most GCMs
- Together, they matters the most for polar surface energy budget and surface climate
 - But through radiative coupling between surface and atmosphere
- The Far-IR matters the most for the LW cloud scattering here
 - The last uncharted territory in the spectral observations



Two far-IR Satellite Missions that I have participated in



GRATING



THERMOPILE



PREFIRE: NASA 4th EV-I mission
\$35M project for 1-year nominal operation
Target Launch date: late 2021/early 2022
Think it as a "far-IR MODIS"

- My role: L2 spectral flux and surface spectral emissivity retrievals, modeling support

→ EARTH EXPLORER-9 USER CONSULTATION MEETING



FORUM: ESA 9th Earth Explorer mission
Current budget ~ 350M euros
Target Launch date: 2025/2026
Fourier Spectrometer with 0.5cm^{-1} resolution

References

- Chen, X. H., X. L. Huang, M. G. Flanner, Sensitivity of modeled far-IR radiation budgets in polar continents to treatments of snow surface and ice cloud radiative properties, *Geophysical Research Letters*, doi:10.1002/2014GL061216, 41(18), 6530-6537, 2014.
- Huang, X. L., X.H. Chen, D. K. Zhou, X. Liu, An observationally based global band-by-band surface emissivity dataset for climate and weather simulations, *Journal of the Atmospheric Sciences*, 73, 3541-3555, doi:10.1175/JAS-D-15-0355.1, 2016.
- Huang, X. L., X. H. Chen, M. G. Flanner, P. Yang, D. Feldman, C. Kuo, Improved representation of surface spectral emissivity in a global climate model and its impact on simulated climate, *J. Climate*, 31(9), 3711-3727, doi:10.1175/JCLI-D-17-0125, 2018.
- Chen, Y.-H., X. L. Huang, P. Yang, C.-P. Kuo, X.H. Chen, Seasonally dependent impact of cloud longwave scattering on the polar climate, submitted.

